MODELLING OF THE CILOC LANDSLIDE IN THE CONSTANTINE CITY UNDER DYNAMIC LOADING BY USING THE PSEUDO STATIC APPROACH

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ABSTRACT

Some landslides types remain still badly explained within the framework of the traditional methods of analysis and instabilities modelling. In this case, new approaches are necessary to give an account of these particular failure modes. We use in this work the Hill's criterion to give an account of these particular failures. Hill's approach in local level and global level is particularly studied, then this approach is established in the computer code by finite elements Plaxis. The application of this approach for nonhomogeneous real problems related to the modelling of the Ciloc landslide in Constantine city in the North East of Algeria under earthquake effect by using of the pseudo static method. The stability analysis of the slope enabled us to highlight the existence of potentially unstable zones.

Keywords: Landslide, Instability, Hill's criterion, Pseudo static method.

1. INTRODUCTION

The natural risks are the subject of significant research, become very active recently. The term of "landslide" includes a variety of phenomena. It is thus possible to find very slow landslide, with maximum displacements of few centimetres a year or, on the contrary, very fast slips: such as "lava" or "torrential muds". The common characteristic to these instabilities is the generation of significant deformations and/or displacements. It is essential to analyze these phenomena in an exhaustive way, i.e. on very variable scales in space and time term of and by taking into account all the possible failure modes.

From a mechanical point of view, the problems of slope stability and landslide have been studied a long time within the framework of the plasticity theory [Hill, 1958; Mandel, 1966; Rice, 1976…].. Historically, the first approaches made the assumption of the associativeness of geomaterials behaviour [Louafa and Darve, 2002]. Other approaches are based on the soil mass equilibrium

(Fellenius method.. .) , [Bishop, 1955; Griffiths, 1999; Junbu, 1968]. The slopes instability was described numerically using two approaches: the plasticity theory on the one hand and the localization theory on the other hand.

New approaches are necessary to take into account these particular failure modes. Locally, the instability is defined within the general framework of the Lyapunov's theory, [Lyapunov, 1907] . Practically, the sufficient Hill's stability condition [Hill, 1958], based on the sign of the second order work could also allow an analysis of instabilities at the local level and global level. These methods are based primarily on the calculation by the finite elements method incorporating the more realistic behaviour models of the geomaterials, [Zienkiewicz and Taylor, 1994]. However, soil instability can appear not only under a localised mode but also under a diffuse mode where the failure is interpreted by an area of chaotic displacements, this failure mode takes place before the localised mode [Servant and al.. , 2004; Khoa and al.. , 2005]. It is this second class of failure which can be described by the stability criterion based on the sign of the second order work [Hill, 1958] that we will present in the nexte.

2. STABILITY ANALYSIS AT THE LOCAL AND GLOBAL LEVEL

Within the framework of elastoplasticity, Hill [1958] shows that the following inequality:

$$\int_V \underline{\dot{\sigma}} : \underline{\dot{\varepsilon}} \, dv \succ 0 \quad \forall \underline{\dot{\varepsilon}} \neq 0 \tag{1}$$

With:

$\underline{\dot{\sigma}}$: the rate stress tensor.

$\underline{\dot{\varepsilon}}$: the rate strain tensor.

d v: the integration volume.

Is a sufficient stability condition, if it is satisfied, whatever the strain and stress fields associated by the constitutive model.

3. SECOND ORDER WORK

Within the framework of associated materials, Hill [1958] expressed a notion of material stability which can be stated as follows: a material element is defined as stable if it satisfies the positivity condition of the second order work:

$$d^2W = \underline{\dot{\sigma}} : \underline{\dot{\varepsilon}} \succ 0 , \qquad \forall \underline{\dot{\varepsilon}} \neq 0 \tag{2}$$

The stability of a solid volume V, called global stability, is assured if the condition [2] is satisfied in each point of volume *V*. This condition implies that the condition [1] is satisfied. This was shown by [Bigoni and Hueckel, 1991] for the more general case of nonassociated materials. Drucker, [1959], then [Mróz, 1963] postulated a sufficient condition of plastic work in term in elastoplasticity:

$$d^2W^p = d\underline{\sigma} : d\underline{\varepsilon}^p \succ 0 , \qquad \forall d\underline{\varepsilon}^p \neq 0 \tag{3}$$

We notice that the material stability condition defined by Drucker [1959] is different from that proposed by Hill [1958]. Indeed, Drucker considered the plastic deformation according to its criterion rather than the total deflection considered by Hill.

In the next paragraph, we introduce and apply the Hill's criterion stability for problems with boundary conditions using the finite element method code, Plaxis [Version 8.4].

4. LANDSLIDE OF THE CILOC SITE IN CONSTANTINE CITY

The five buildings of the Ciloc are located in South-western edge of the Koudiat-aty plate. A slip has affected, since February 1987, the slope (weak slope, 10 to 15 %) with the foot of the building B (figure 1). The cartography of this slip shows that wrenching at the head, which presents an arched form, with setbacks of 1 with 2.5m, extends at a distance from 60 m. It passes from 2 to 3 m of the south-western angle of the building. The axis of the slip corresponds appreciably to alignment surveys S9, S2, S3 (figure 2). The slip extends towards south-west on a hundred from meters length. Inclinometric measurements have makes it possible to locate the slip surface to a 4 m depth in the survey S2 and to 7.9 m in the survey S3 [Benaissa and al., 1989].

Figure 1. buildings of the Ciloc site.

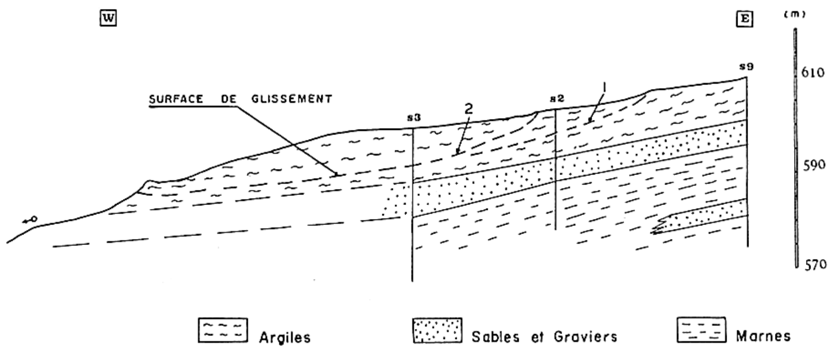


Figure 2. Cross on the axis of slip [Benaissa et al., 1989].

5. STABILITY OF THE SITE UNDER EARTHQUAKE

We will be interested in the behaviour and the stability of a nonhomogeneous problem under earthquakes using the pseudo static method. It will be a question of an application of the Hill's stability criterion in order to analyze the effects of a strong amplitudes earthquake which can strike the Constantine city. The adopted earthquake for this study is that of October 27, 1985.

1. **Earthquake characteristics**

Recently, Constantine city was severely shaken by an earthquake. Its magnitude Ms = 6.0 occurred on October 27, 1985 at 19:34:59. The epicentre whose direction was 36°34 ' N, 6°65' E, was located at the North of the EL Khroub village [Bounif and al, 1987]. Spectral accelerations for a damping rate 5 %, are presented on figure 3. These spectra show that amplifications are more significant in the N–S direction than in the E-W direction. However, the answer spectrum corresponding to the vertical component shows that the movement was damped.

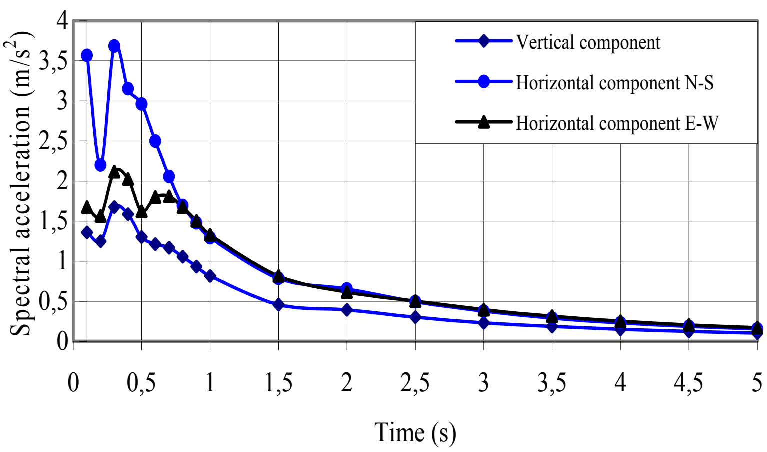


Figure 3. Accelerogrammes of response spectra with a damping of 5 %.

6. NUMERICAL MODELLING OF THE CILOC LANDSLIDE BY THE PSEUDO STATIC APPROACH

We study this slip of Ciloc, using the Hill's criterion such as it was introduced previously. A pseudo static simulation will be undertaken. The loading corresponds to the application of a constant acceleration (horizontal or vertical has $a_g = k_c.g$), k_c is the seismic coefficient and g is the gravity acceleration, such as it can occur during the earthquake. In a pseudo static approach, the cyclic seismic movement is replaced by a constant acceleration has a_g. The components of the pseudo static forces applied to the solid mass of soil are equal to the product of the acceleration components and the material weight. The N-S section of the Ciloc slope is selected in order to study the instability phenomenon. The first phase of calculation consists of the application of gravity. Then, we apply to the solid mass the maximum acceleration values measured in the N-S slope direction.

1. **Geometrical and numerical model**

The analysis is made on the assumption of the plane strain, the site is modelled by a bidimentional vertical cut, it has a trapezoidal shape, the morphology of the soil is characterized by low declivities which vary from 12 % to 15 %. The slope extends to a 400 m length and a variable height from 10 m, in the left hand side to 80 m in the right hand side (figure 4). The model is discretized by a finite elements mesh of 1859 triangular elements (15 nodes, 12 integration points) that is to say 15267 nodes.

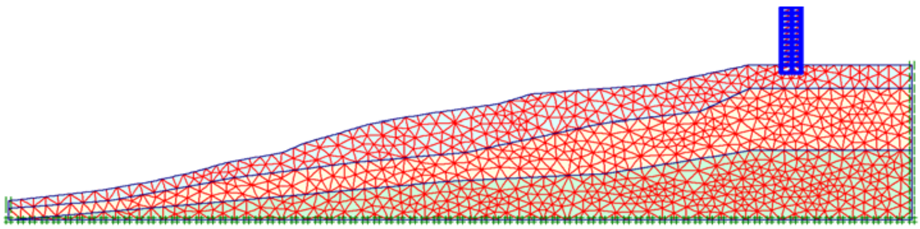


Figure 4. Geometry, mesh and kinematics boundary conditions.

2. **Boundary conditions**

The conditions in displacements (kinematics) are also presented on figure 4. We impose zero-displacements according to the X-axis on the left and the right of the medium limits and zero-vertical displacements according to the Y axis on the bottom of the solid mass.

3. **Initial conditions**

Modelling is realised in two calculation phases, the first phase is intended to apply the studied slope gravity (initial state). In the second phase, we apply the pseudo static forces taking account the horizontal acceleration components $a_{gh} = 0.30g$ and the vertical component $a_{gv} = 0.20g$. This phase is automatically divided into several acceleration increments.

6.4 **Behaviour model and mechanical characteristics**

The slope behaviour is modelled with elastoplastic model HSM [Hardening Soil Model, Schanz and al, 1999] incorporated in the PLAXIS software. The principal model parameters for the three materials types are summarized in table 1.

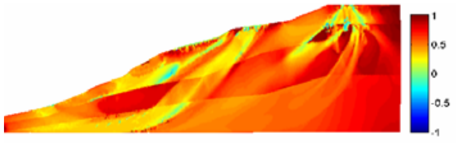
7. MATERIAL STABILITY ANALYSIS IN TERM OF THE LOCAL SECOND ORDER WORK

In the Figure 5 we present the isovalues of the of the local second order work for four values of imposed acceleration (0.0967g, 0.1363g, 0.146g and 0.148g). We observe clearly that the area with negative values of the second order work extends proportionally with the increase of the k_c coefficient. This area starts initially on the slope free face, and then extends strongly in depth affecting the two higher layers to the foot of the slope.

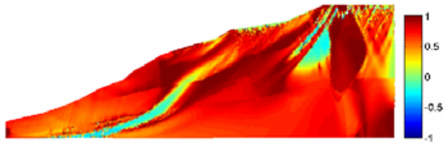
Table 1. Geotechnical Characteristics of the Ciloc site soil.

Layers	Clay	Gravels sand	Marle
Dry density γ_d (kN/m ^{3})	21.0	17.0	18.6
Wet density γ_h (kN /m ^{3})	23.0	20.0	21.2
Effective Cohesion c' (kN /m ^{2})	7.0	1.0	13.0
Friction angle φ' (°)	24.0	35.0	20.0
Dilatancy angle ψ (°)	0.0	10.0	0.0
E_{50}^{ref} (kn/m^2)	38000	30000	28000
E_{ur}^{ref} (kn/m^2)	150000	90000	60000
E_{oed}^{ref} (kn/m^2)	38000	30000	28000
Poisson ratio ν	0.30	0.20	0.25

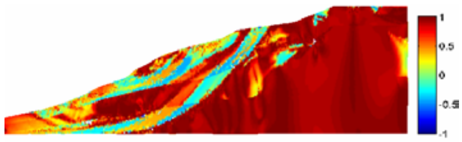
The Hill's criterion can thus correctly describe the slip areas which have affected the slope under the pseudo static forces due to imposed accelerations. The large obtained area with negative values of the local second order work make us to think of an instability of the solid mass at the global level. The following paragraph is thus presented to study this question using the Hill's criterion at the global level.



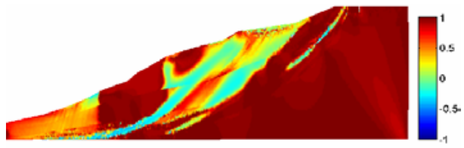
(a) $kc = 0.0967$



(b) $kc = 0.1363$



(c) $kc = 0.146$



(d) $kc = 0.148$

Figure 5. Isovalues of the second order work of the four increments of imposed acceleration.

8. GLOBAL STABILITY ANALYSIS IN TERM OF THE GLOBAL SECOND ORDER WORK

The figure 6 presents the evolutions of the global second order work with respect to the acceleration increase with the seismic coefficient kc.

The seismic coefficient, which is automatically calculated by PLAXIS software, varies in a nonuniform way. By drawing the normalized global second order work $D^2 W_{norm}$ (figure 6), we observe that $D^2 W_{norm}$ decrease with increasing the acceleration. This decrease reflects well the fact that the pseudo static forces increasing due to accelerations has destabilized the slope. When the acceleration exceeds the value of 0.1363g (figure 6), a brutal fall of the $D^2 W_{norm}$ value occurs. The loss of positivity of the global normalized second order work with the last acceleration increments indicates a loss of stability on the global scale of the solid mass according to Hill's criterion.

9. CONCLUSIONS

A modelling of the Ciloc slope was realised with the HSM model of PLAXIS software using a pseudo static approach. The cyclic seismic movement is replaced by a constant acceleration the pseudo static forces applied to the solid mass of soil are equal to the product of the acceleration components and the

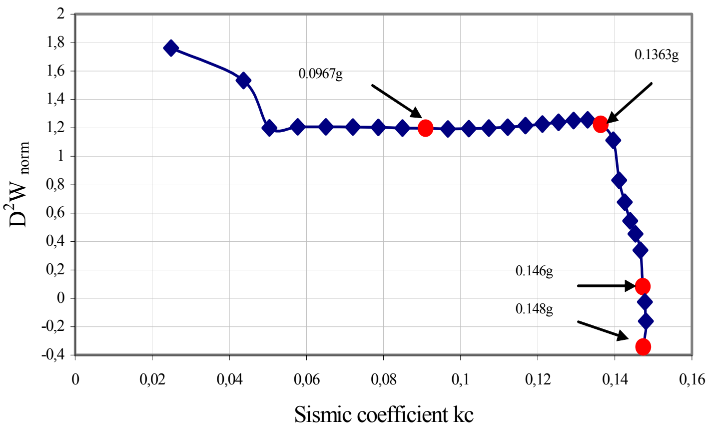


Figure 6. Evolutions of the work of the second standardized total order.

material weight. By drawing the isovalues of the local second order work d^2W, we observed a large area of negative values compared to the real slip-circle of the slope. Concerning the global instability of the solid mass, the layout of the global second order work evolutions allowed to detect it. Indeed, the reduction of the global normalized second order work D^2W_{norm} expressed has the fact that the pseudo static forces increasing due to accelerations destabilized the solid mass.

10. References

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